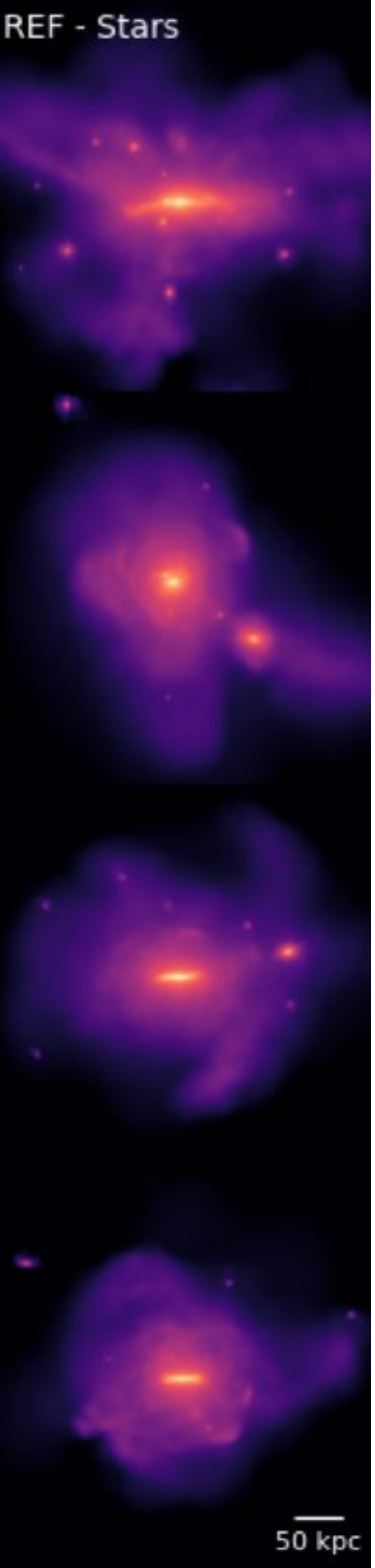


Stellar halos of Milky Way-like galaxies in Eagle high resolution simulations

Andreea Font

Ian McCarthy

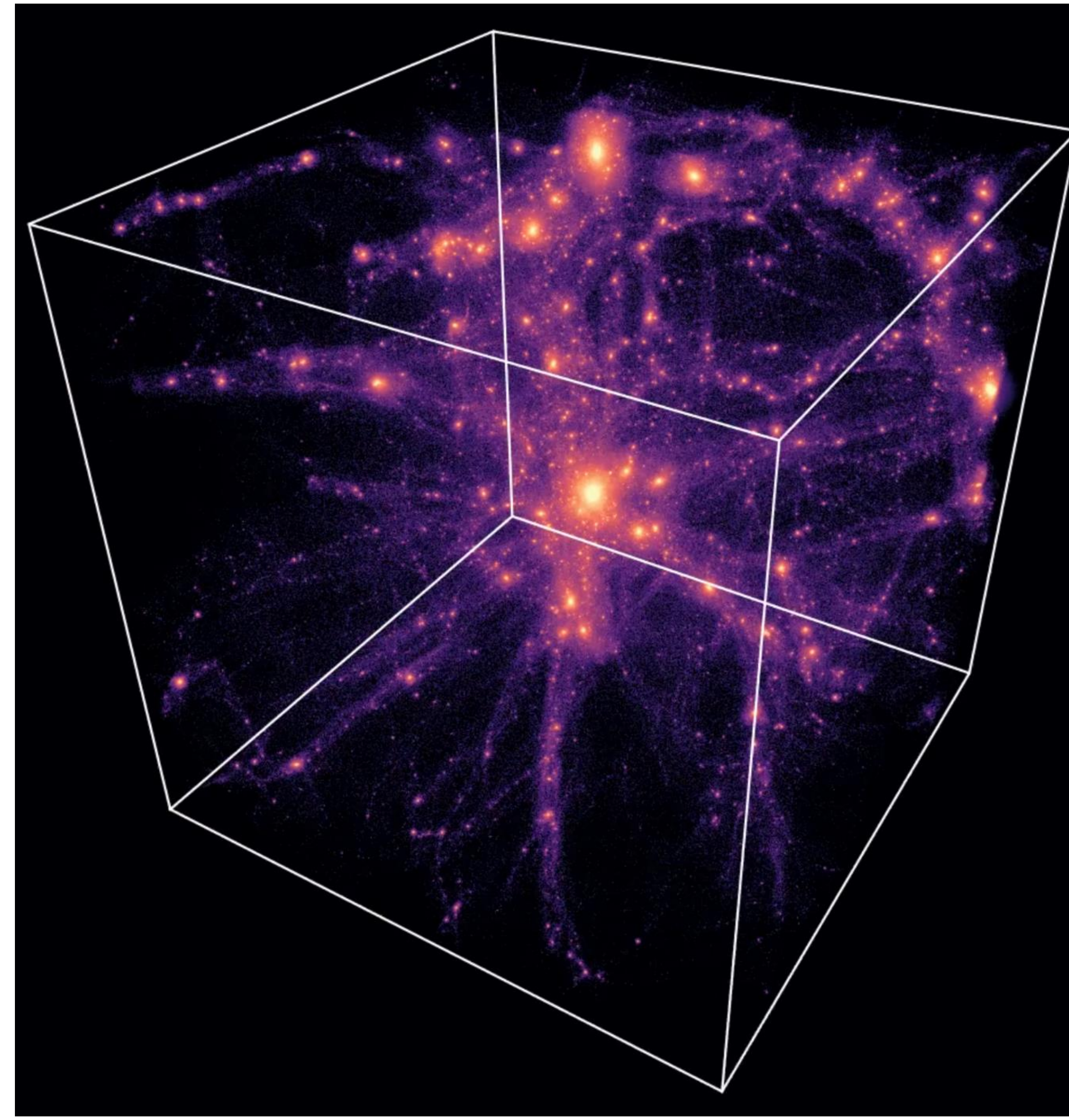
(Liverpool John Moores University, UK)

+ **the Eagle Team**

Eagle:

gas-dynamical cosmological simulations

- include prescriptions for star formation, stellar feedback, AGN, black hole formation, chemical enrichment.



100 Mpc box: Ref – L100N1504 ("Reference")

25 Mpc box: Recal –L025N0752 ("Recalibrated")

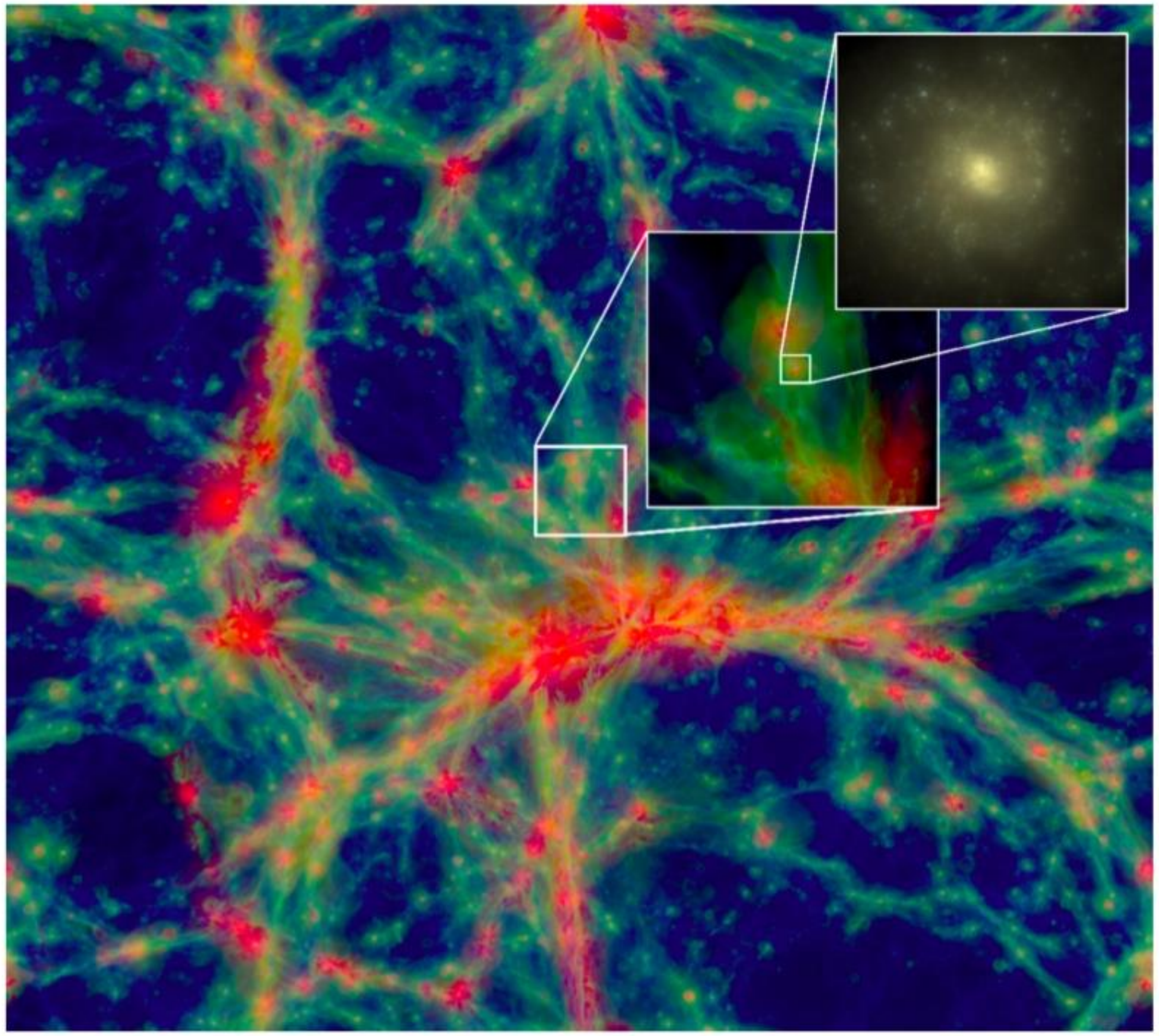
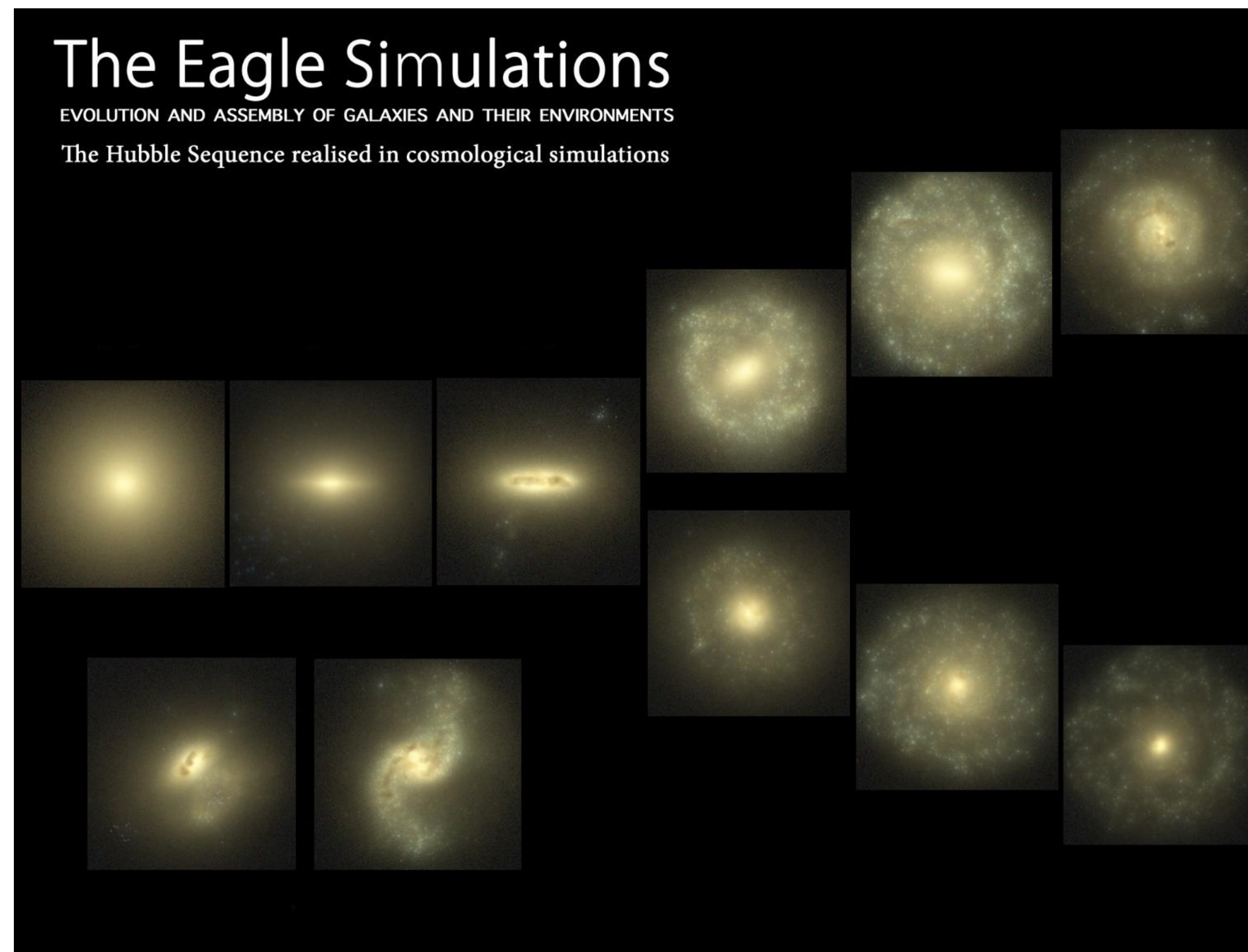
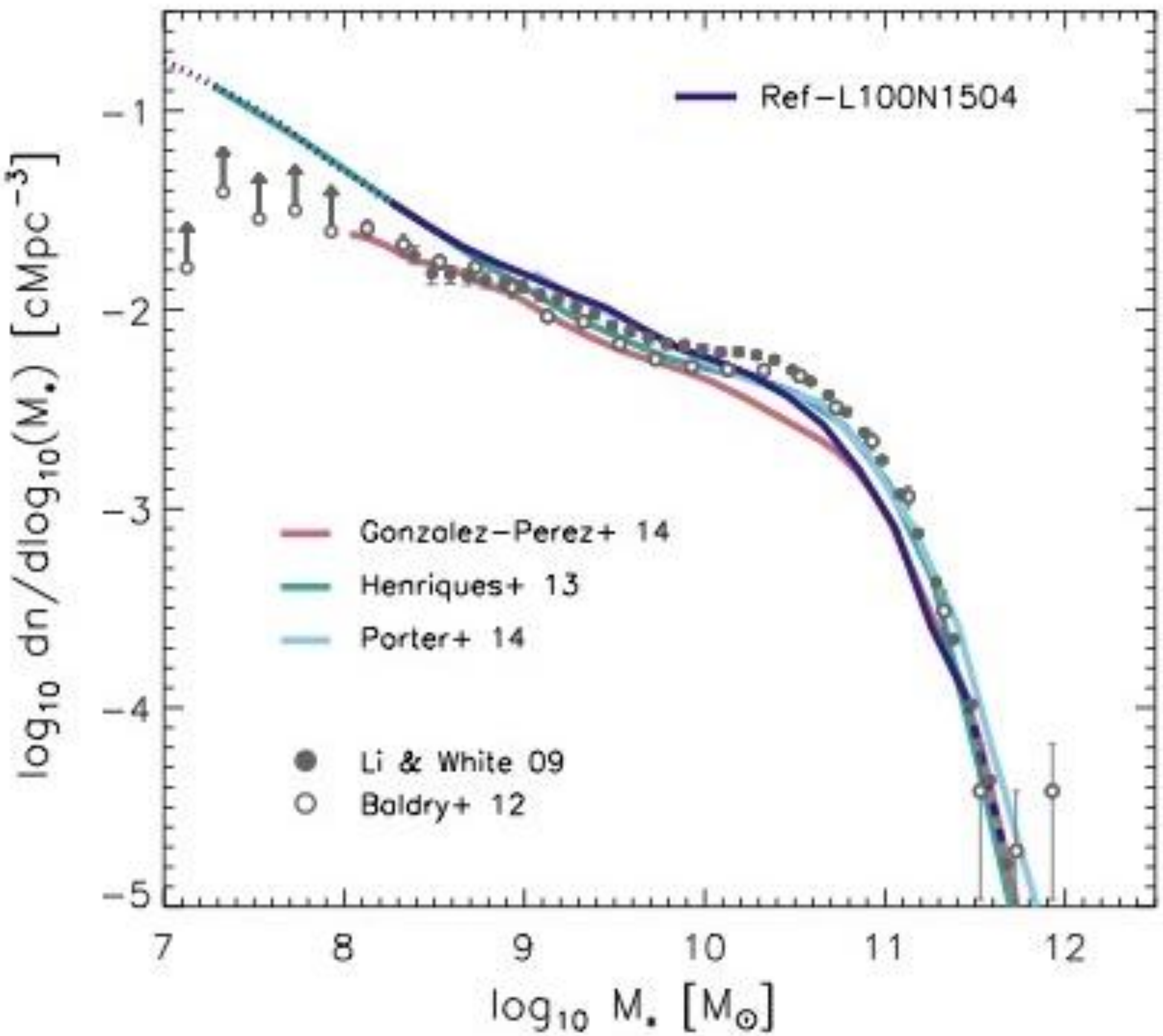


Figure 1. A $100 \times 100 \times 20$ cMpc slice through the Ref-L100N1504 simulation at $z = 0$. The intensity shows the gas density while the colour encodes the gas temperature using different colour channels for gas with $T < 10^{4.5}$ K (blue), $10^{4.5}$ K $< T < 10^{5.5}$ K (green), and $T > 10^{5.5}$ K (red). The insets show regions of 10 cMpc and 60 ckpc on a side and zoom into an individual galaxy with a stellar mass of $3 \times 10^{10}\,M_{\odot}$. The 60 ckpc image shows the stellar light based on monochromatic u, g and r band SDSS filter means and accounting for dust extinction. It was created using the radiative transfer code SKIRT (Baes et al. 2011).

Eagle simulations reproduce the observed variety of galaxy morphologies.

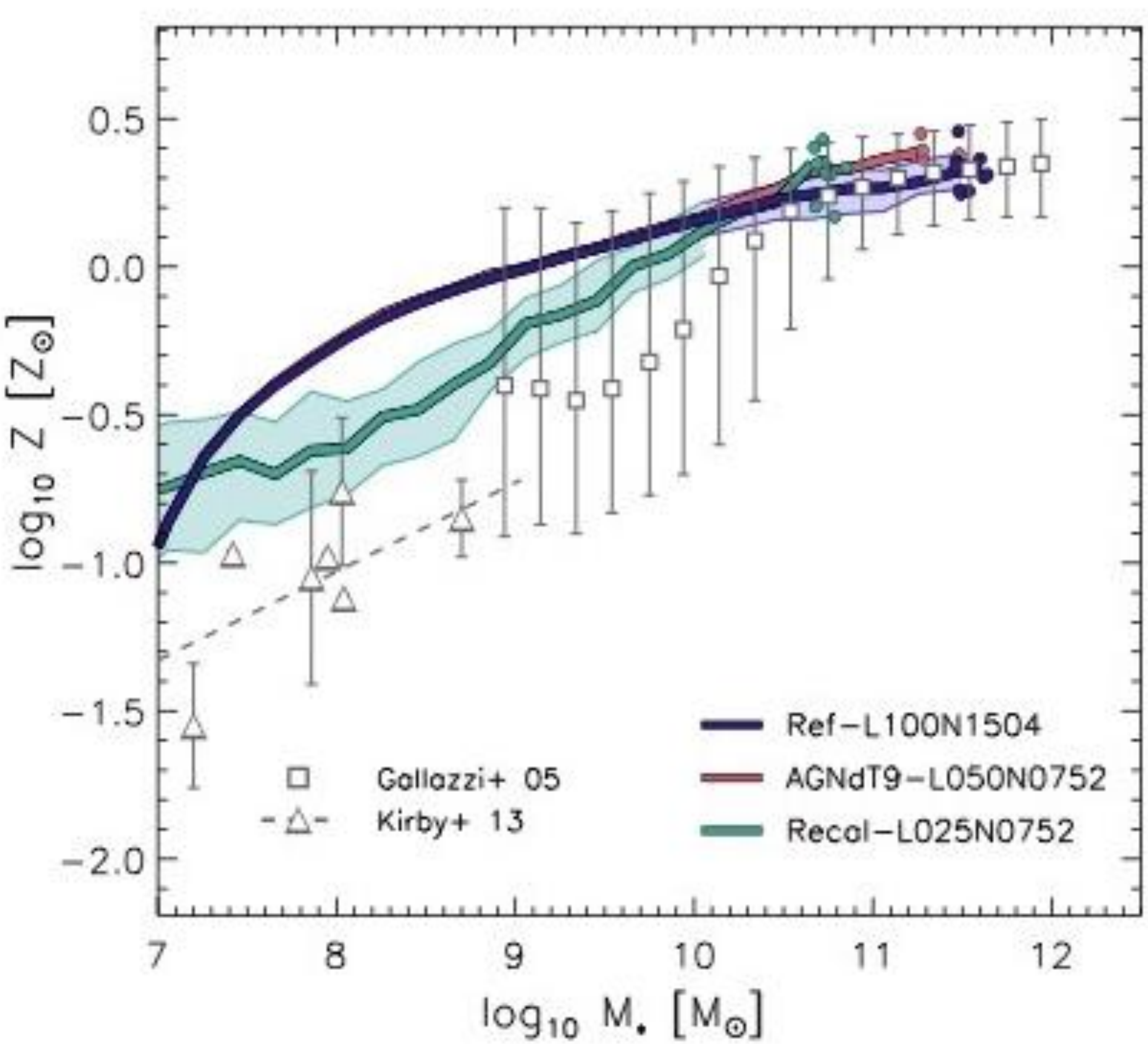


Eagle simulations match a broad range of galaxy scaling relations and galaxy global properties, e.g. the **stellar mass function**:



(Schaye et al 2015)

or the **stellar mass – metallicity relation**:



Schaye et al (2015)

Using stellar haloes to understand galaxy formation

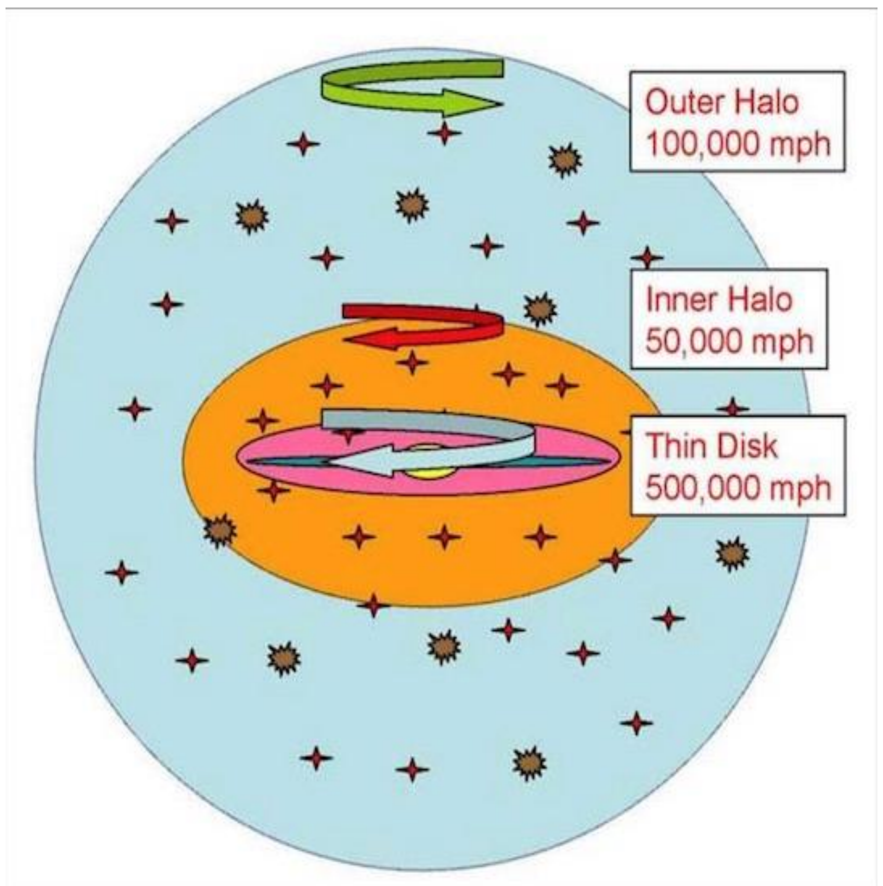
How do stellar haloes form?

Two competing theoretical models:

- mainly through accretion
- in situ + accretion (‘dual nature’).

Models do not always agree on
origin of the in situ stars:

- stars ejected from the disc /heated discs
- stars formed from gas stripped from satellites
- stars formed in filaments of cooling gas



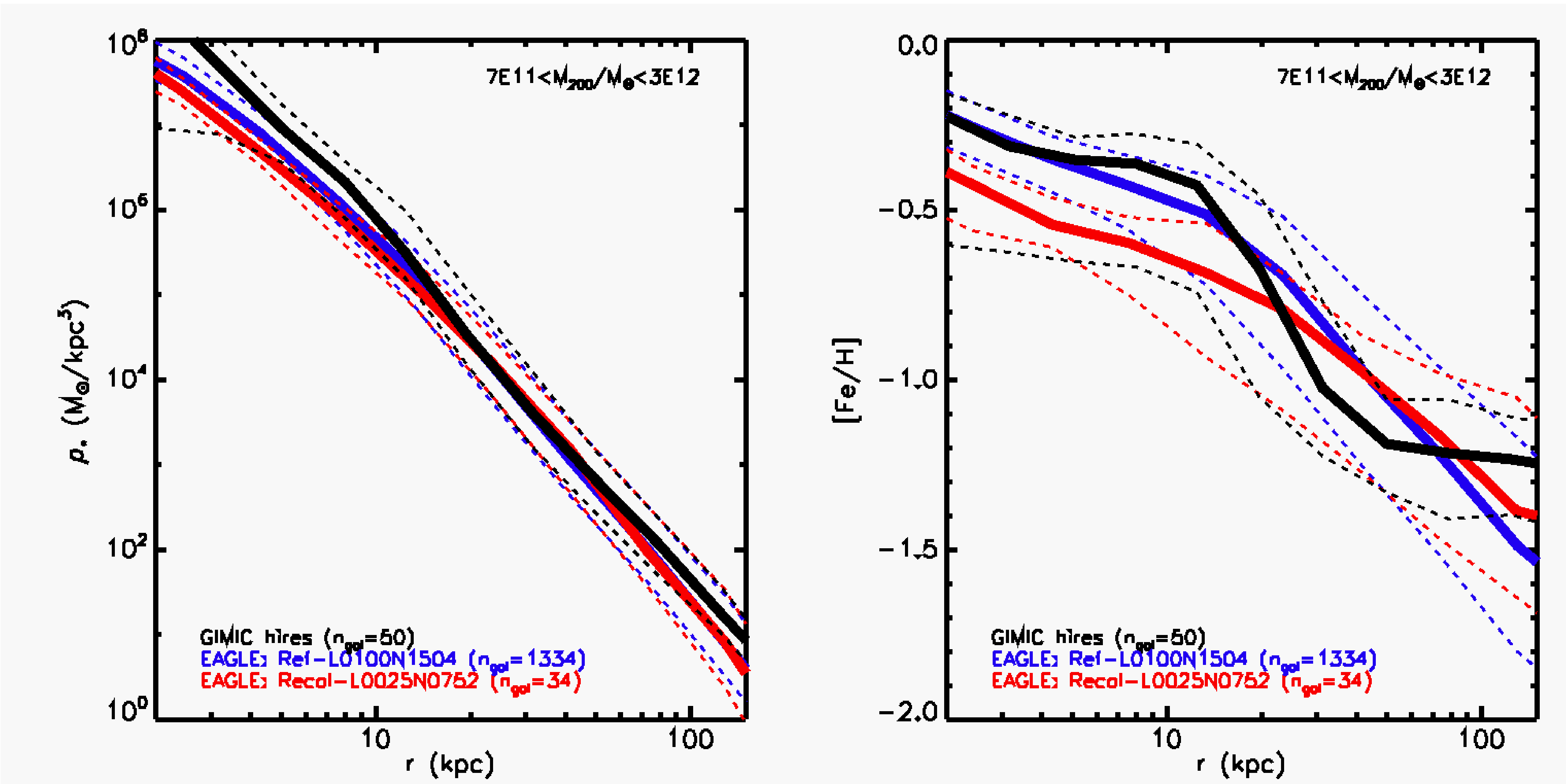
Using stellar haloes to understand galaxy formation

How can we test this? Compare with observations:

- **[Fe/H] or colour gradients in stellar haloes**
- **breaks** in surface brightness profiles
- **stellar haloes mass/light fractions**
- probe the **signatures in the kinematic and chemical abundance** space of accreted and in situ stars
- compare the properties of **tidal streams** in simulations with observations (number, kinematic properties, spatial distribution, chemical abundances).

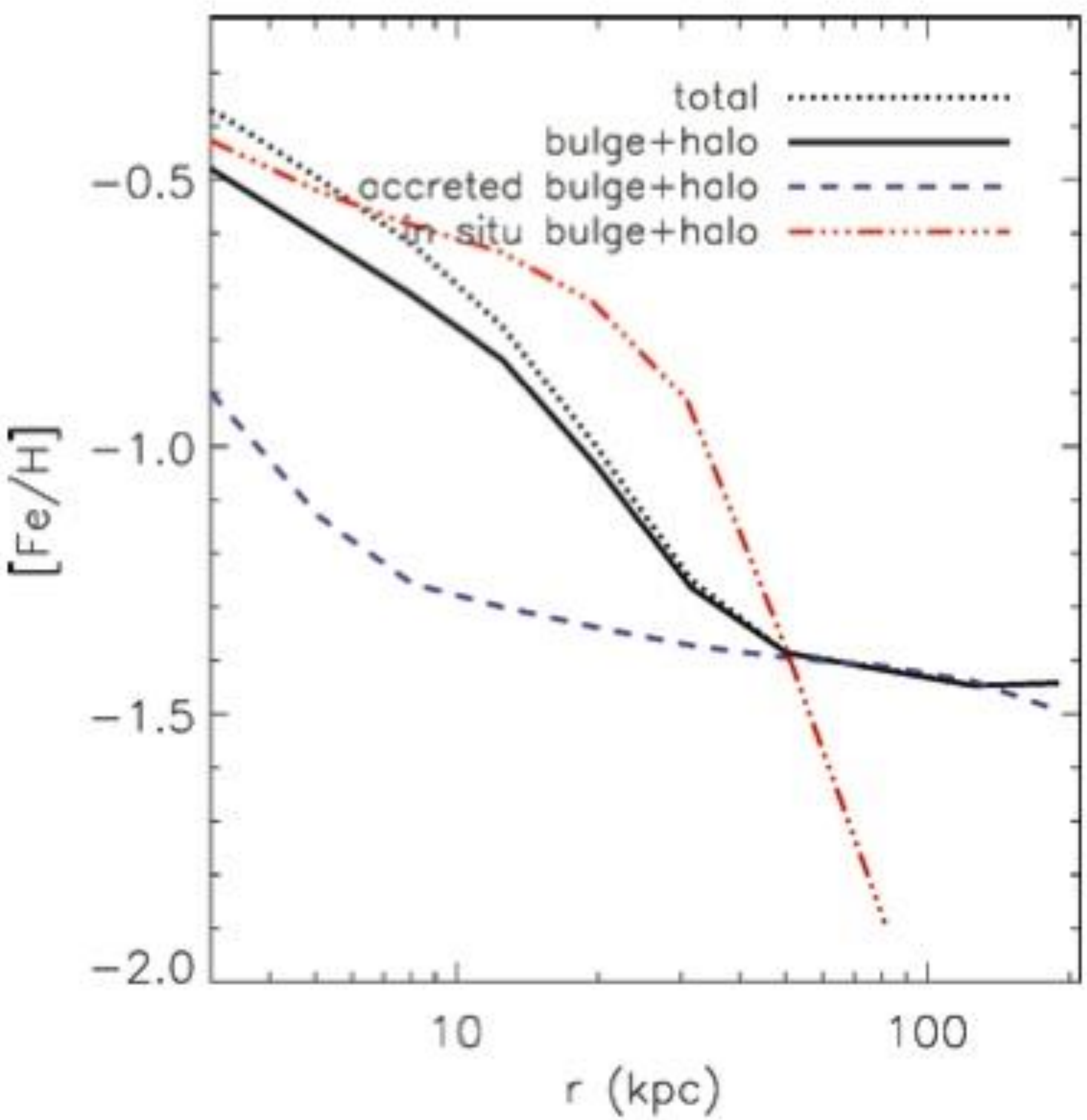
Eagle:

\> 1000 MW-type galaxies in Eagle 100 Mpc box
34 MW-type galaxies in the 25 Mpc box



GIMIC: 50 MW-type galaxies (Font et al. 2011)

(Spherically averaged) [Fe/H] gradients are the result of the **dual nature of stellar halos.**



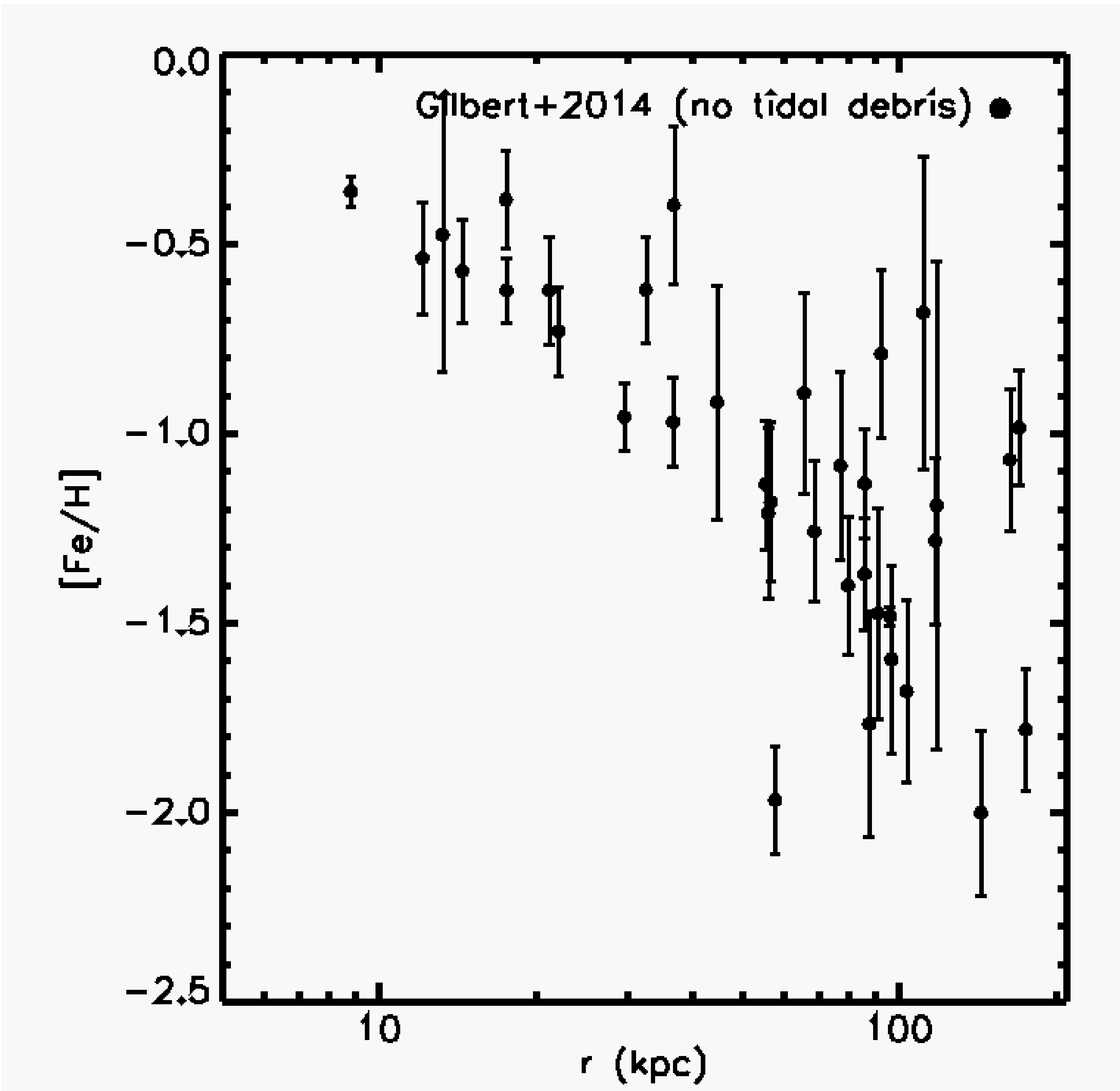
Font et al (2011)

In situ stars are:

- more centrally concentrated
- more metal rich
- rotate (slowly) with the disc

Observations: are metallicity gradients universal?

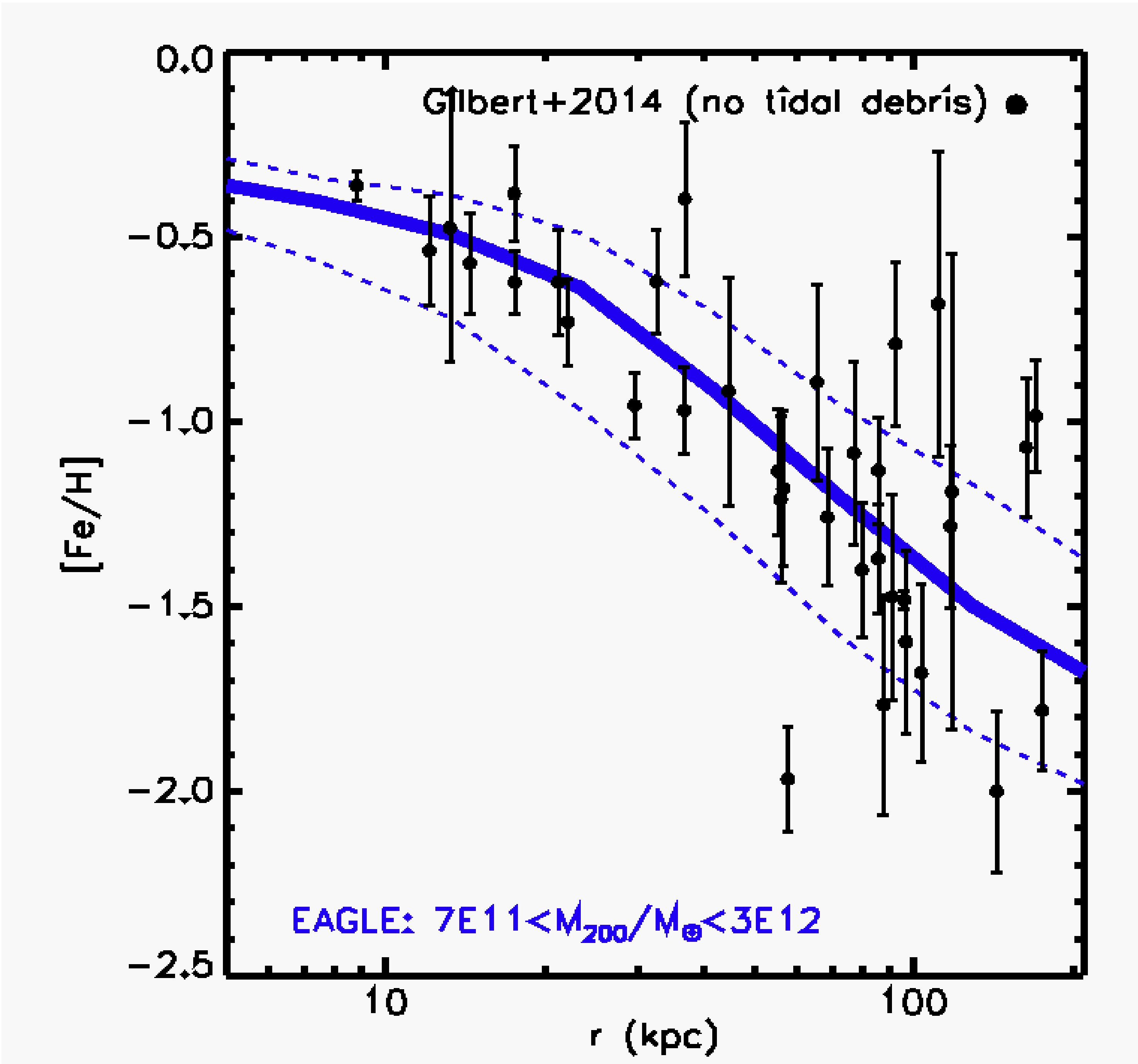
A global [Fe/H] gradient is seen in M31:



[Fe/H] data in M31

(SPLASH survey, Gilbert et al 2014).

Eagle: universal (spherically averaged-) metallicity gradients



The averaged [Fe/H] profile of L* galaxy haloes in the EAGLE sims

matches the

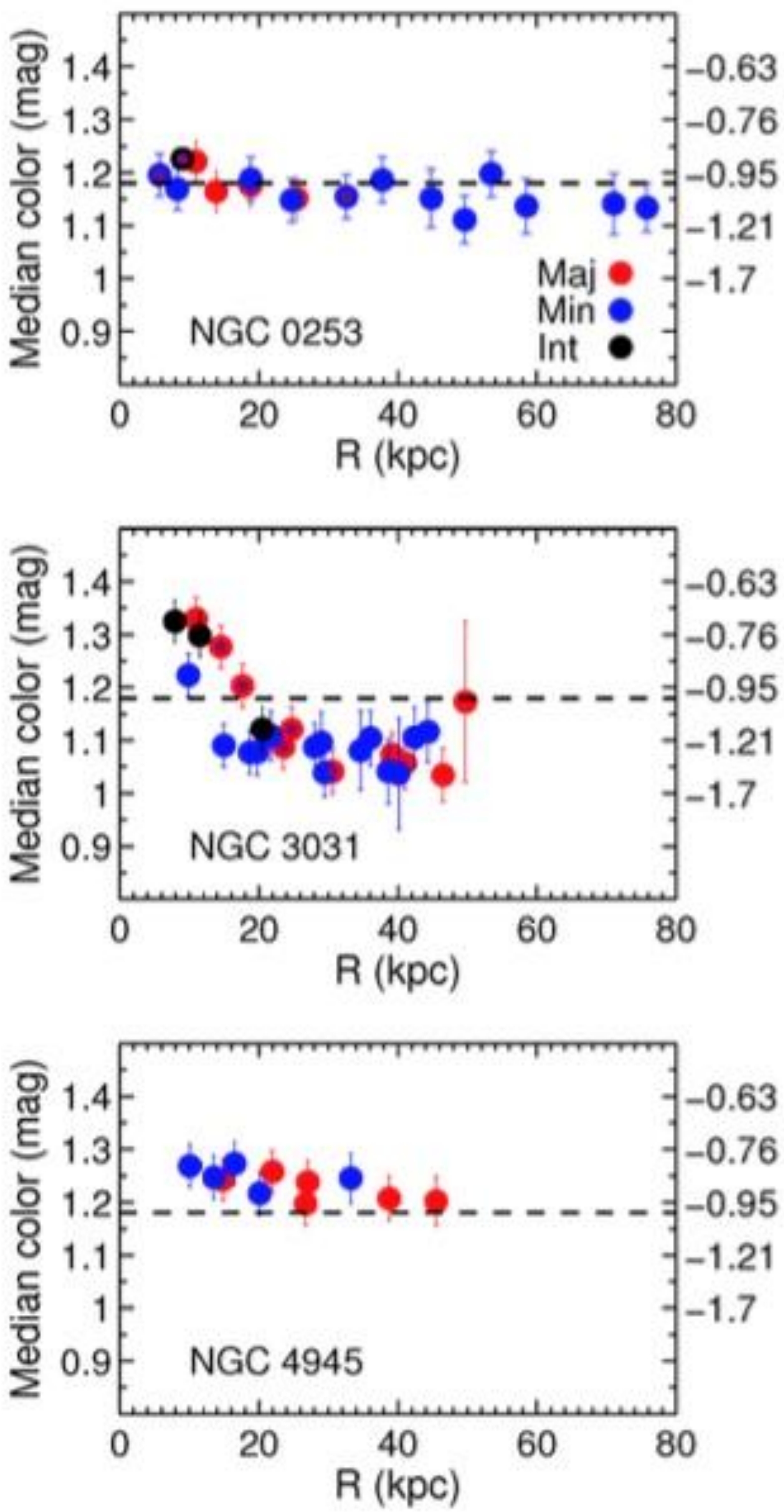
[Fe/H] profile in M31

(SPLASH survey, Gilbert et al 2014).

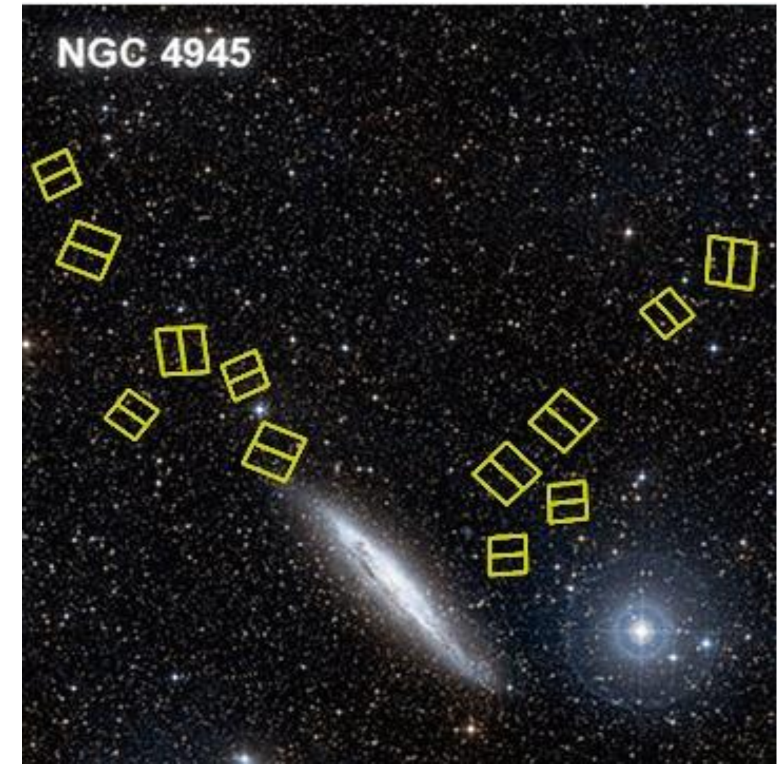
Global gradients are also seen in other gas-dynamical simulations e.g. GIMIC (Font et al 2011); see also Tissera et al 2014; Cook et al 16.

No universal metallicity gradients?

Some galaxies show *no colour gradients* (3/6 in the GHOSTS sample)

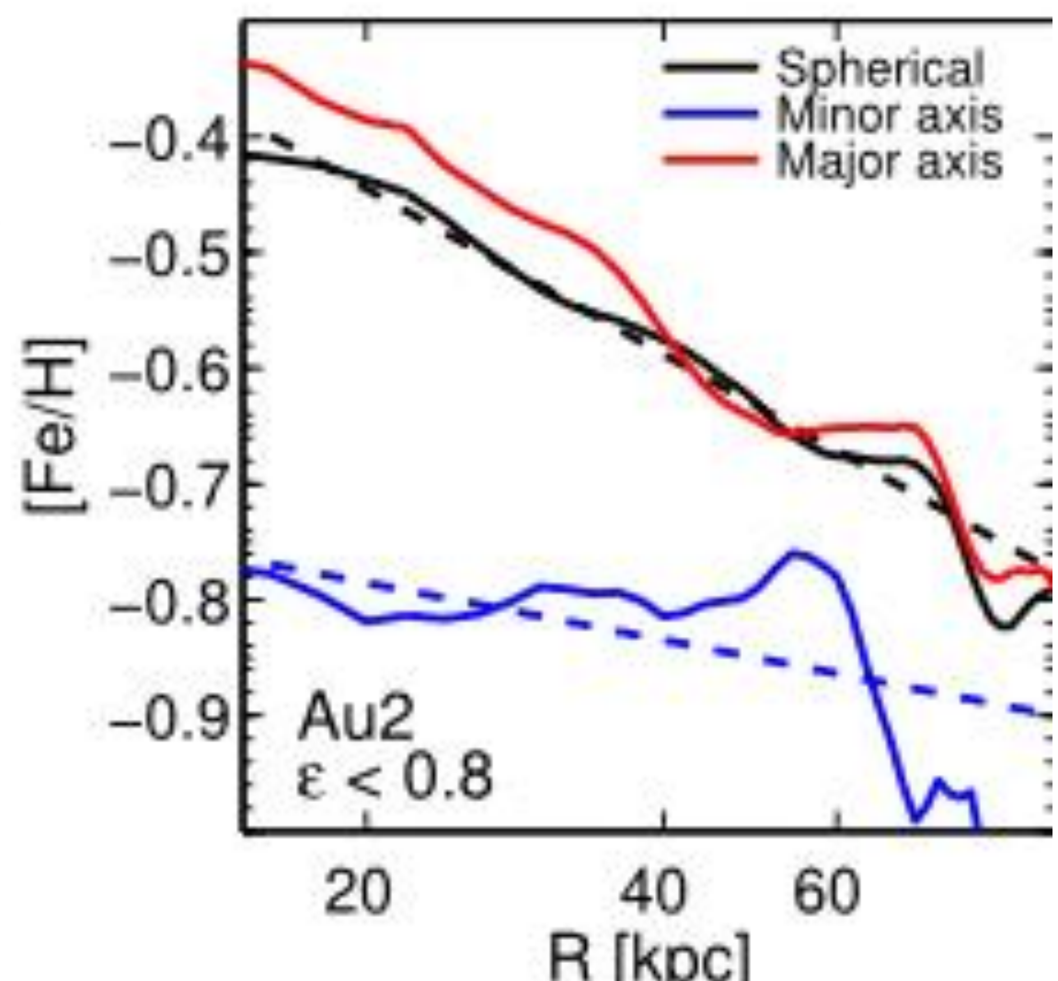


(Monachesi et al 2015)



The Auriga gas-dynamical simulations show weaker (no?) [Fe/H] gradients along the minor axes.

(Monachesi et al 2016)



Zoomed Simulations of Milky Way-type galaxies:

a new set of disc galaxies resimulated with Eagle (Font et al., in prep).

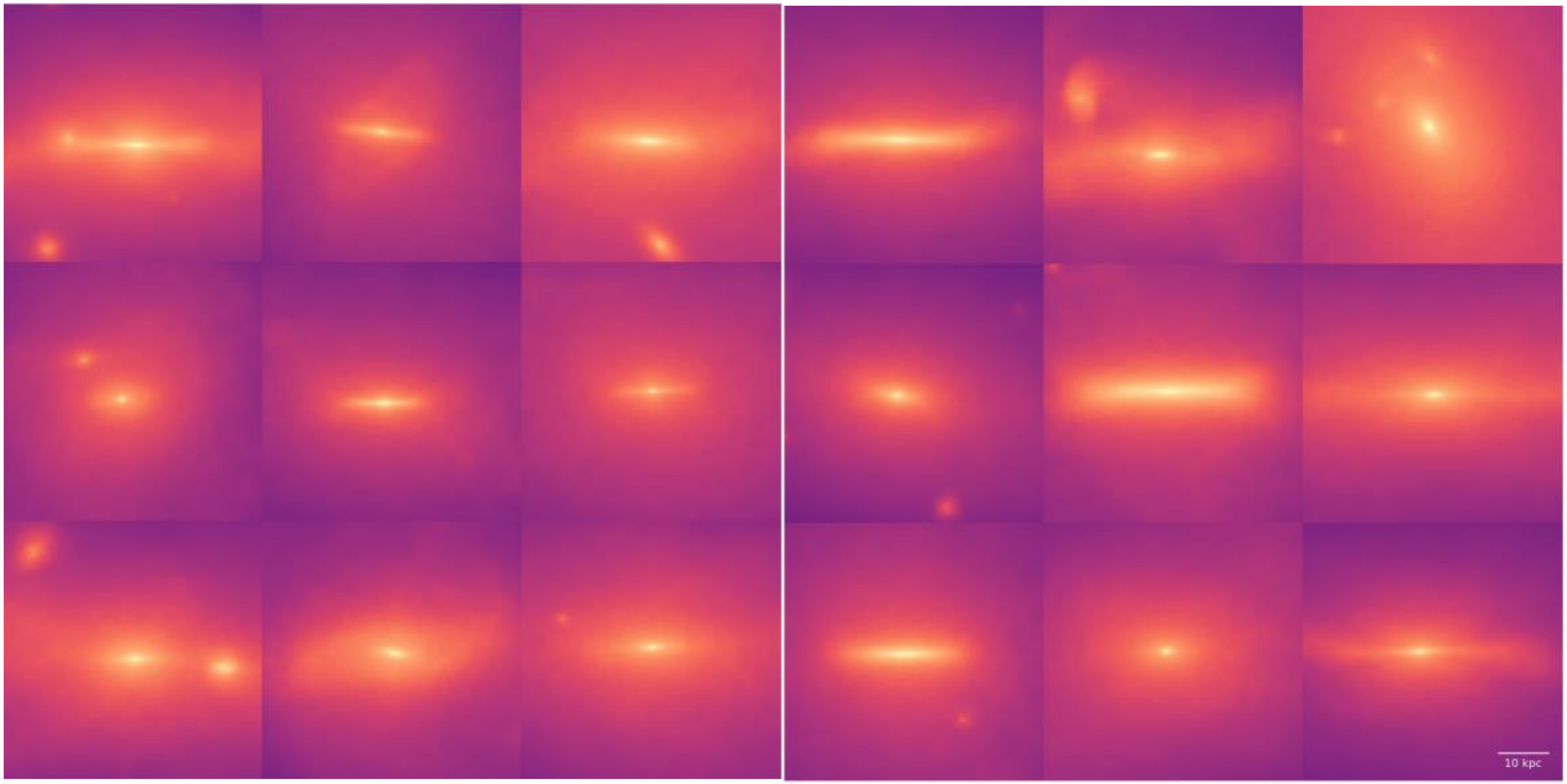


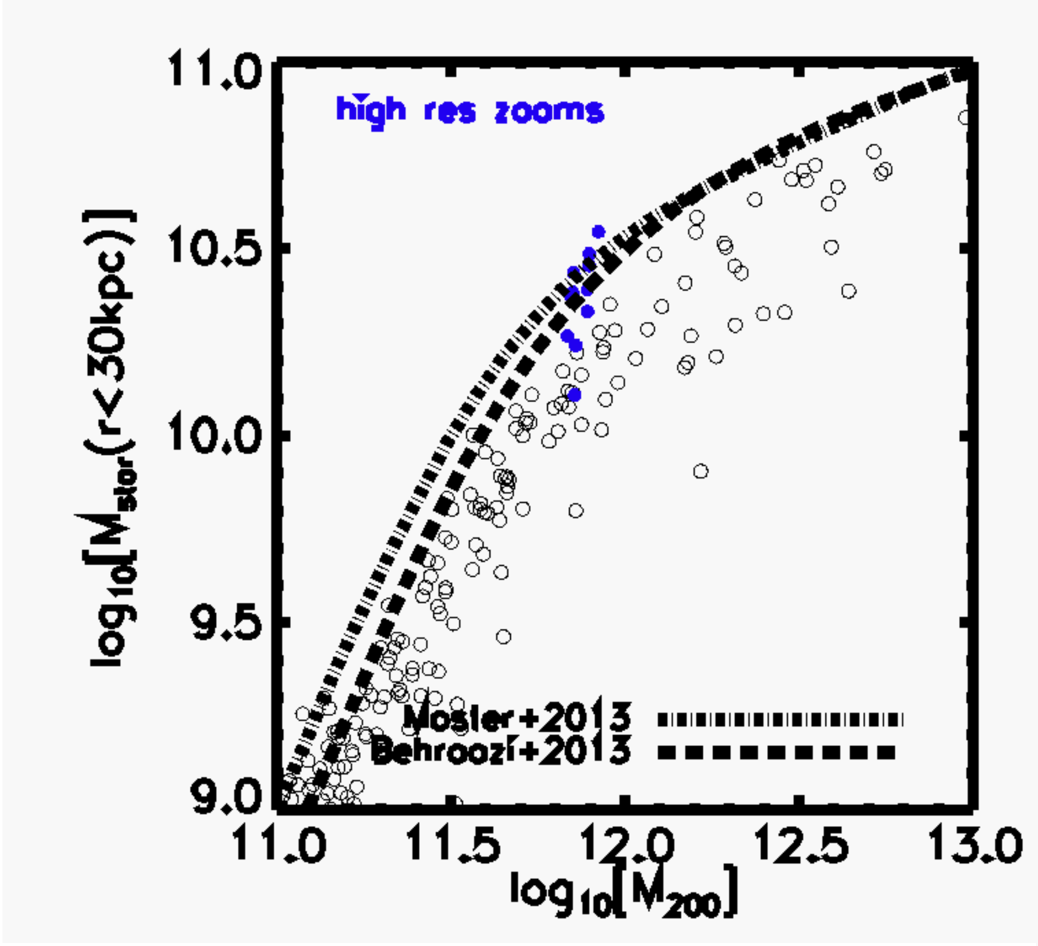
Image credit: Robert Poole-Mckenzie (LJMU)

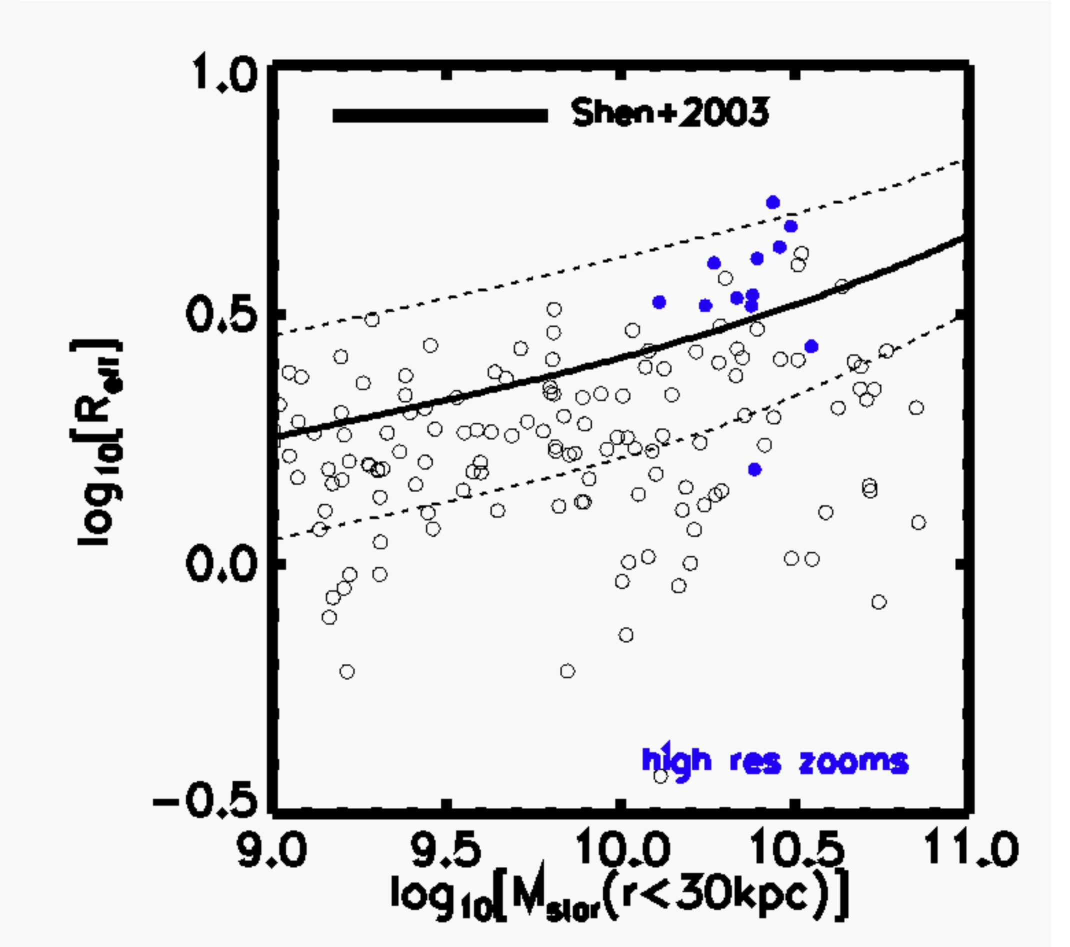
- >20 disc galaxies in the MW-mass range (7 x 10^{11} M_{Sun} – 3 x 10^{12} M_{Sun}).
- run with the 'Eagle code', but with a recalibrated SN feedback model.
- particle resolution: m_{star} ~ 10^4 M_{Sun} , m_{dm} ~ 1.68 x 10^5 M_{sun}.

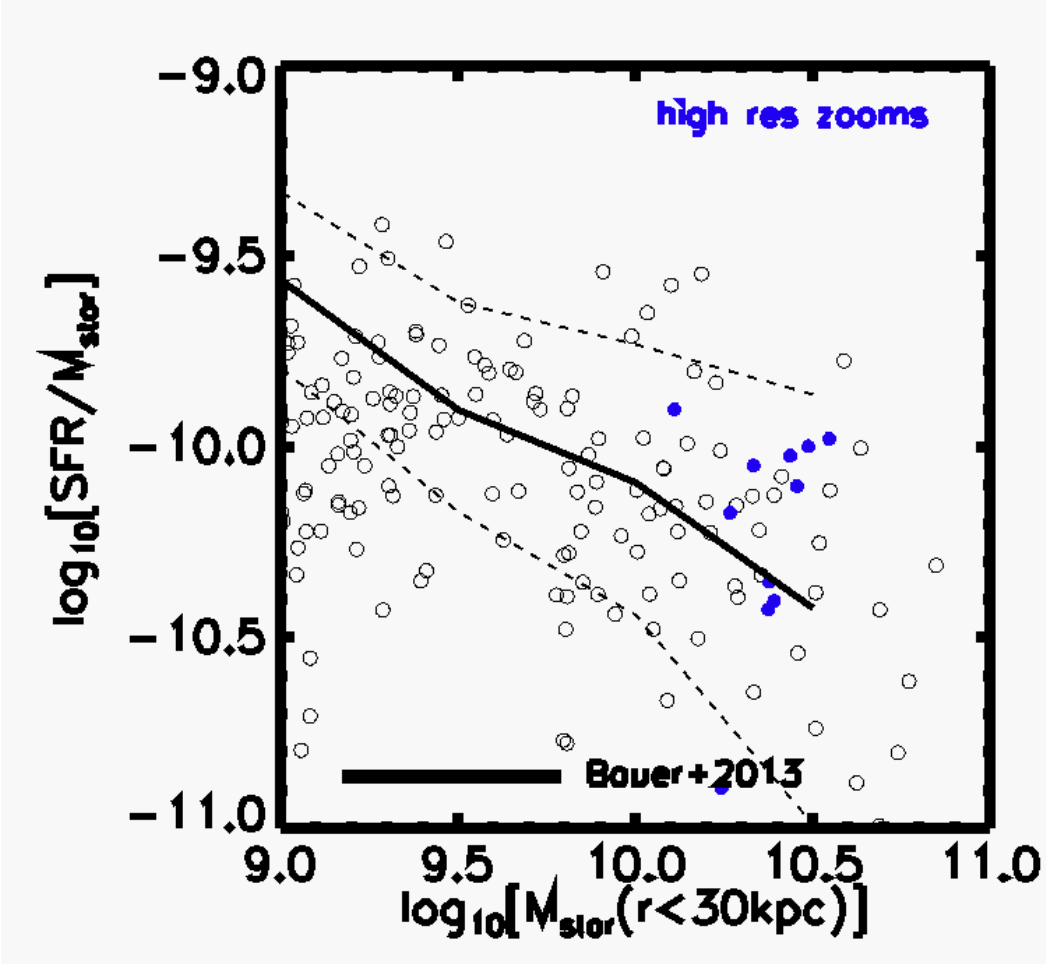
Match to the global scaling relations:

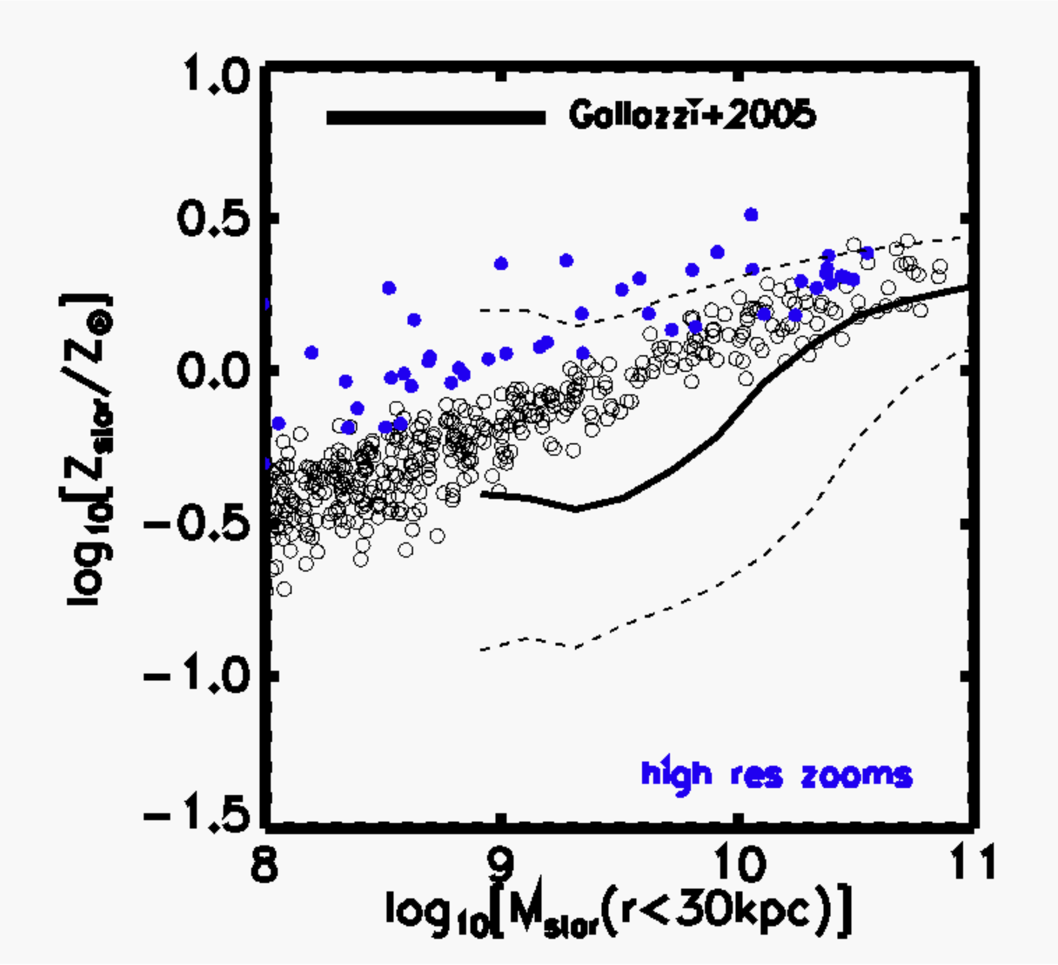
- M_{halo} – M_{star} relation
- Galaxy sizes - M_{star}
- sSFR – M_{star}
- M_{star} – Z relation.

(Font et al, in prep).

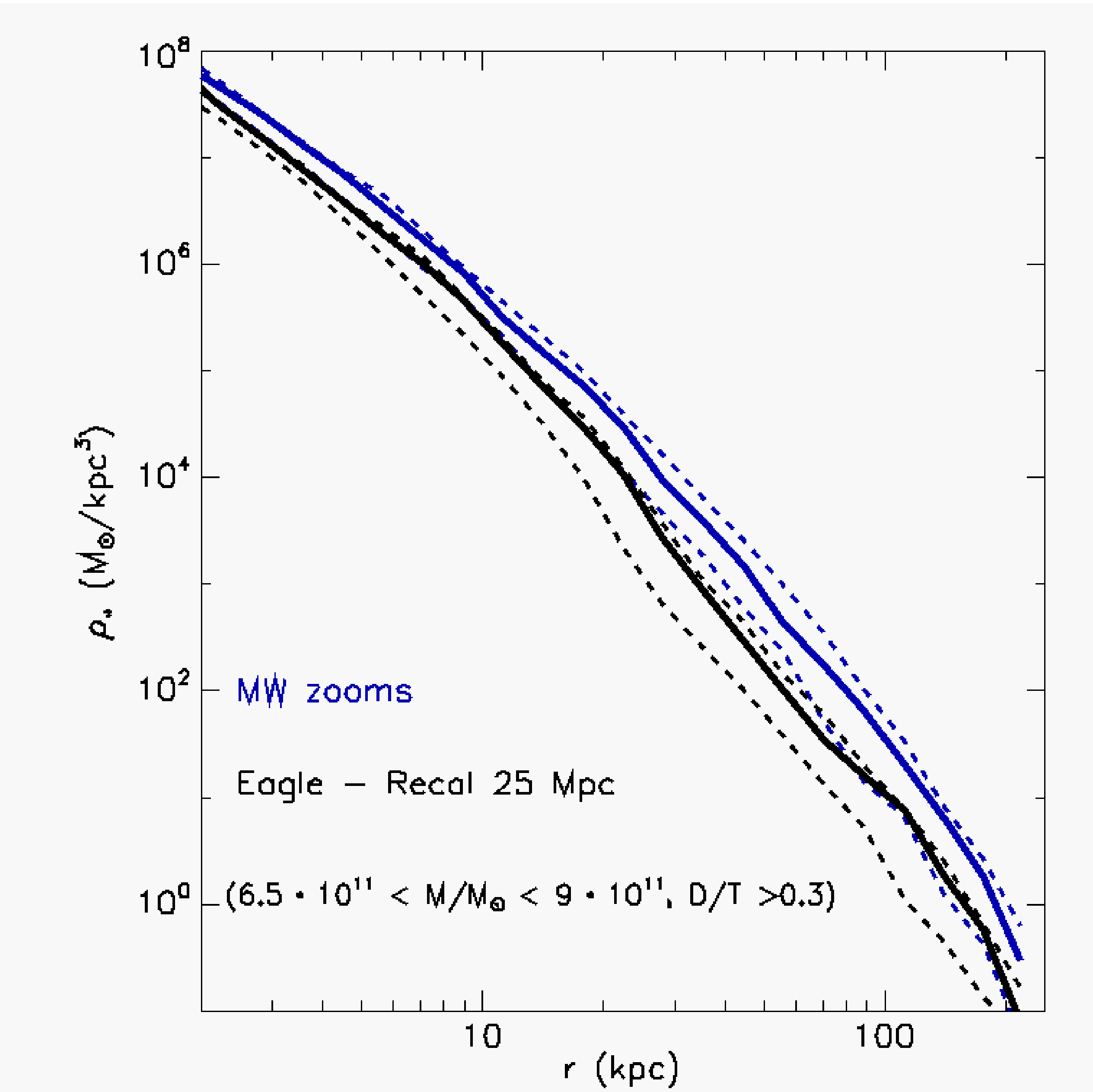


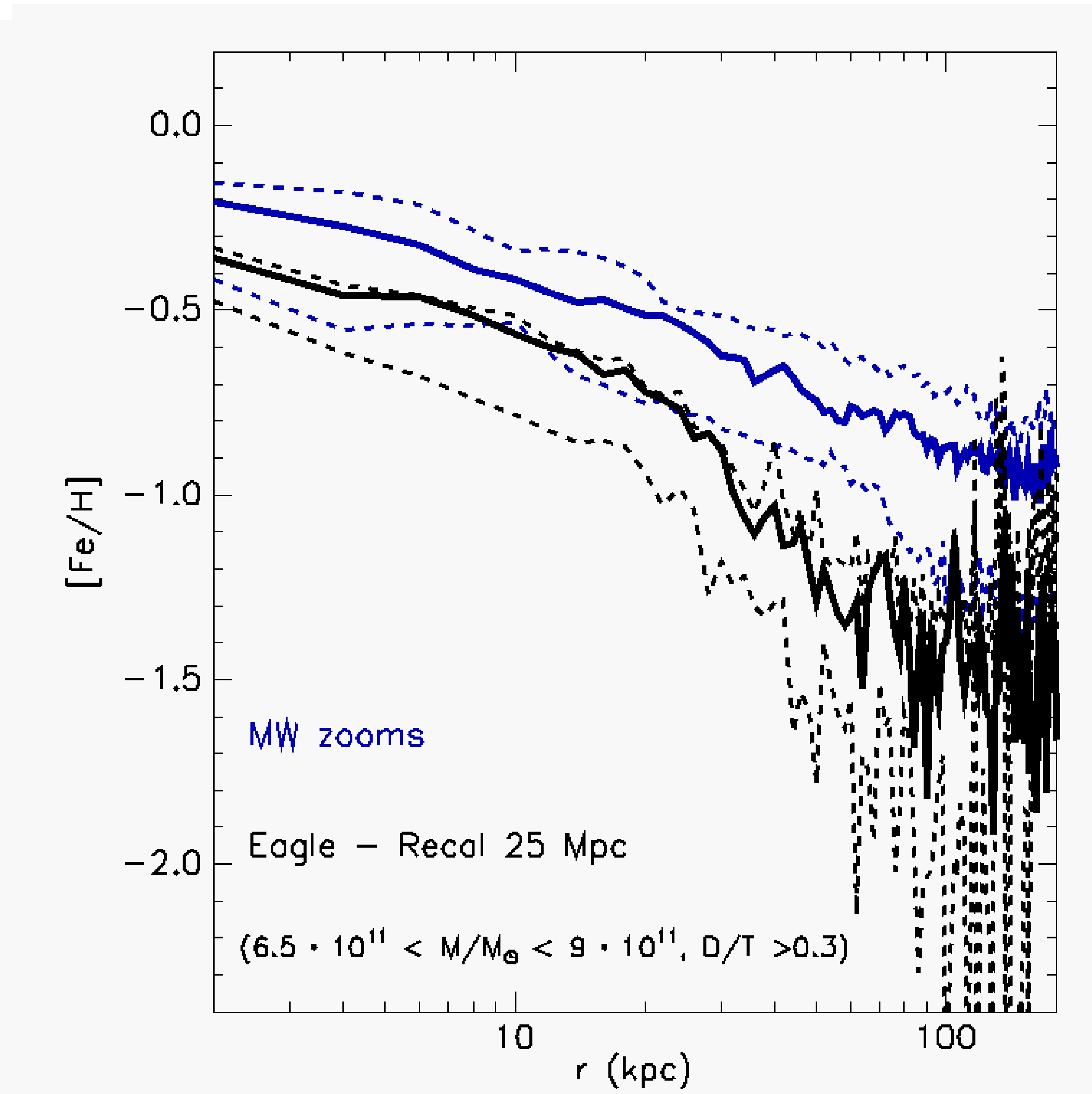






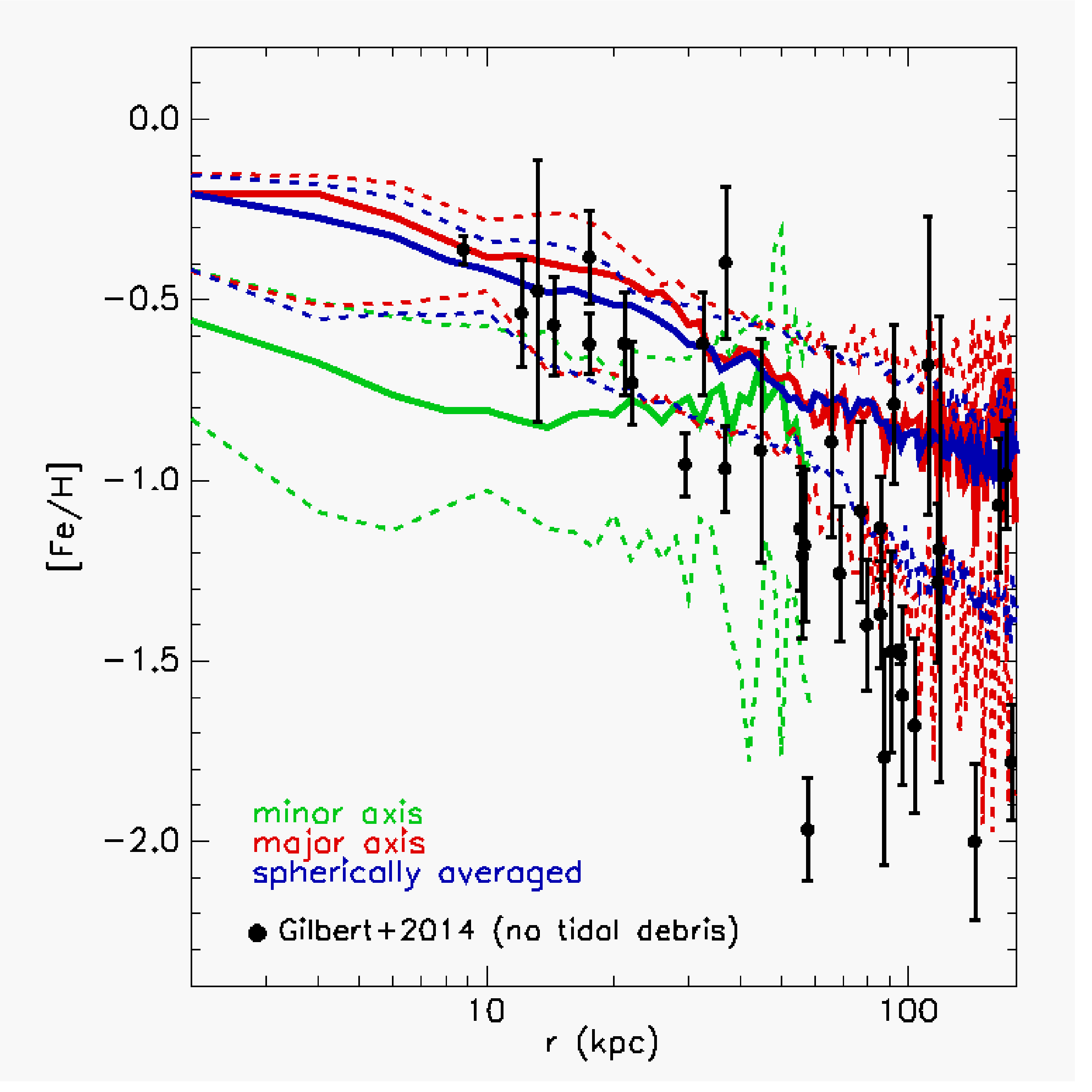
Global properties of MW-mass stellar halos in the Eagle (25 Mpc) simulation vs. halos in the Eagle MW zooms:





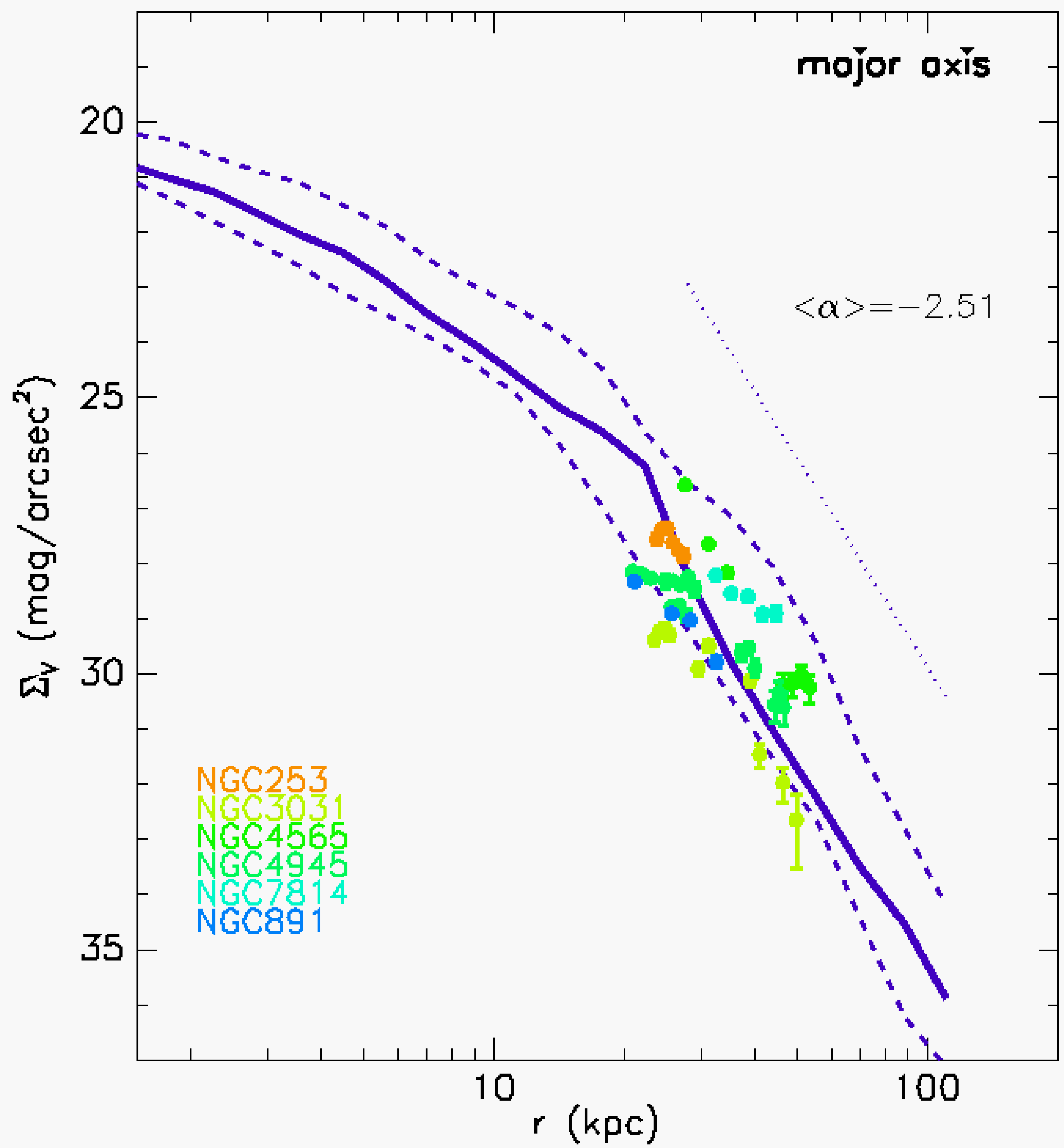
Eagle MW zooms vs observations:

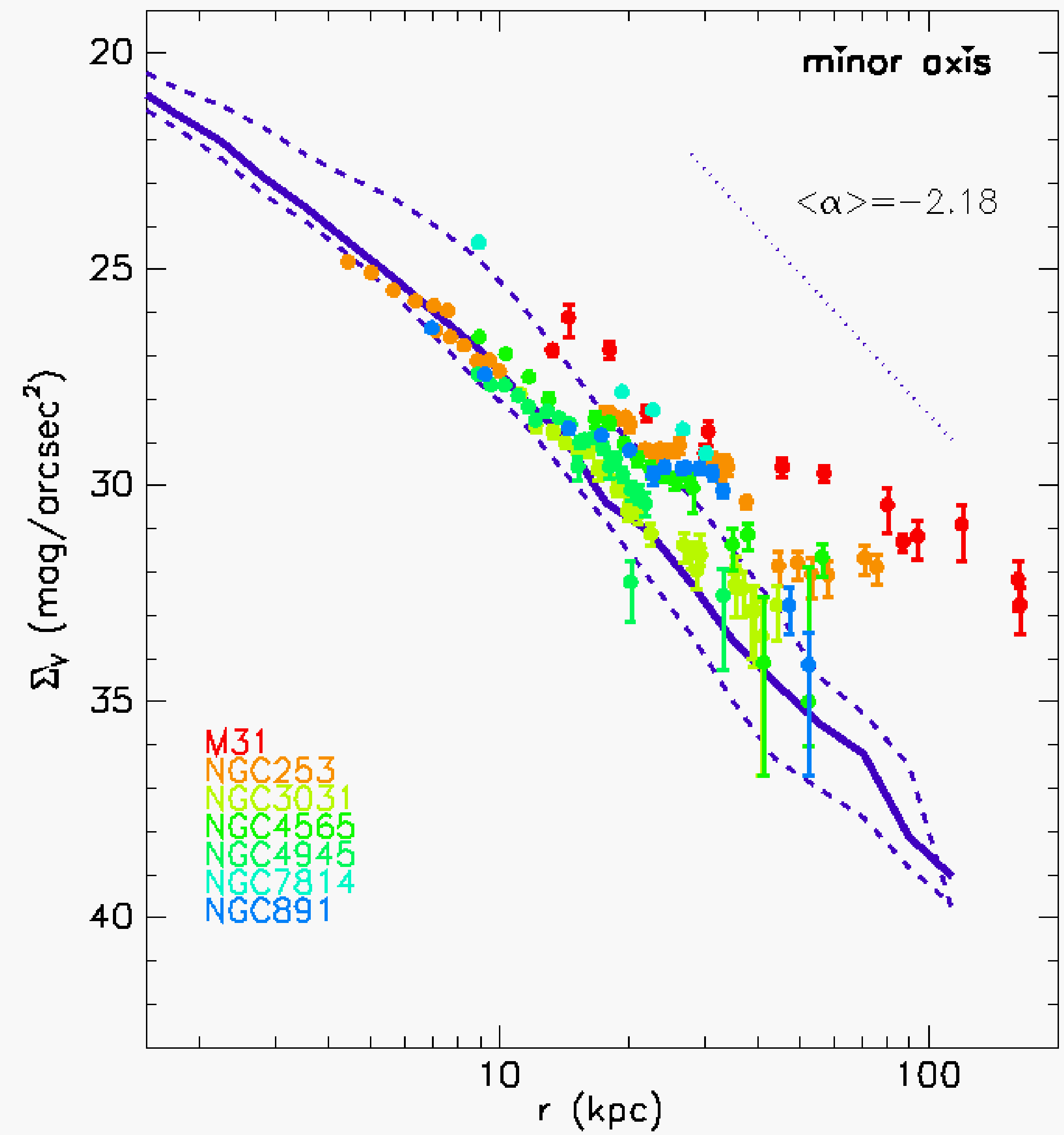
1. [Fe/H] profiles



- stronger [Fe/H] gradients along the major axis (**~0.75 dex**).
- weaker the [Fe/H] gradients along the minor axis, but still significant **(~0.4 dex).**

2. Breaks in the surface brightness profiles. Outer slopes.

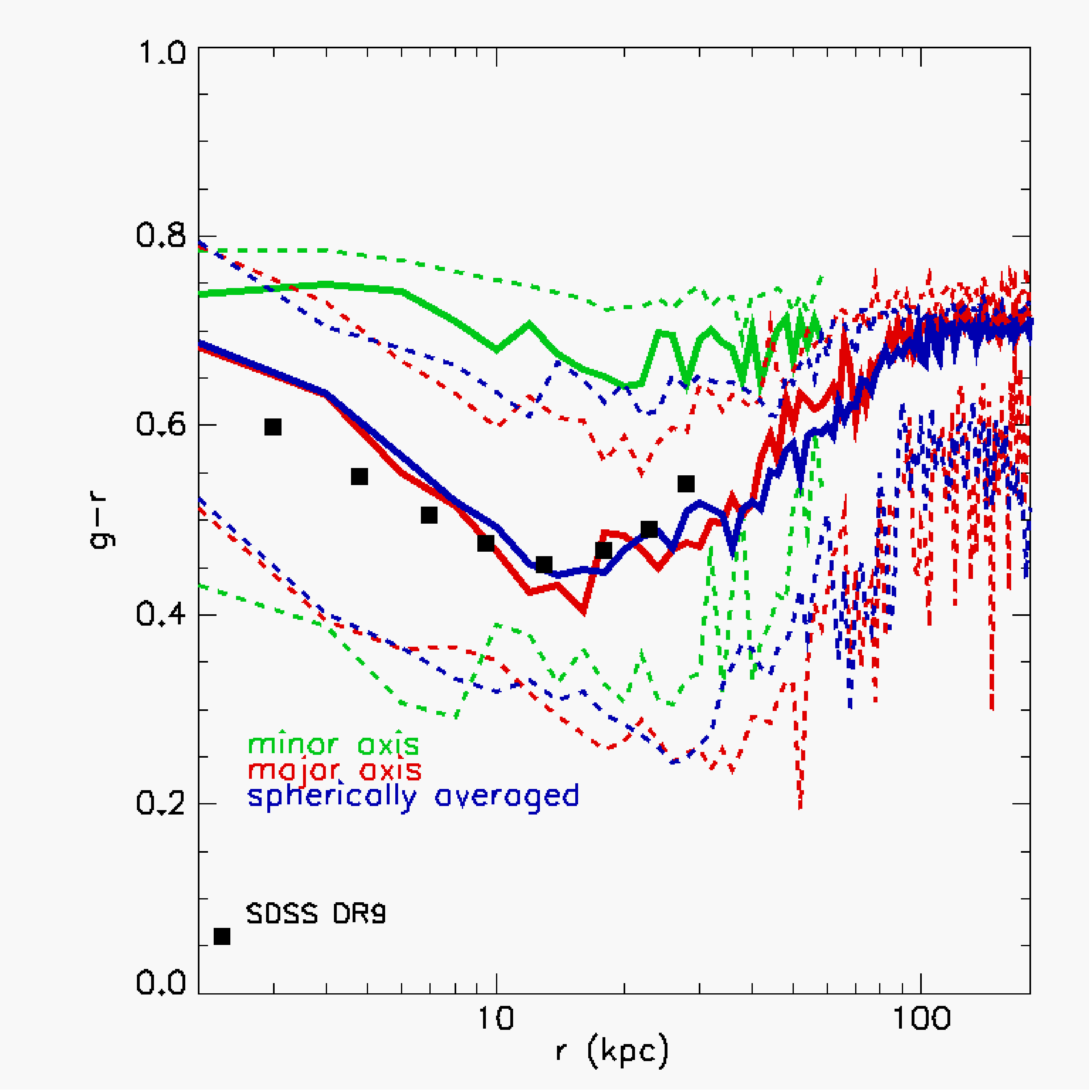




- Obs. data from the GHOSTS survey (Harmsen et al 2017) and SPLASH (M31).

3. Colour profiles:

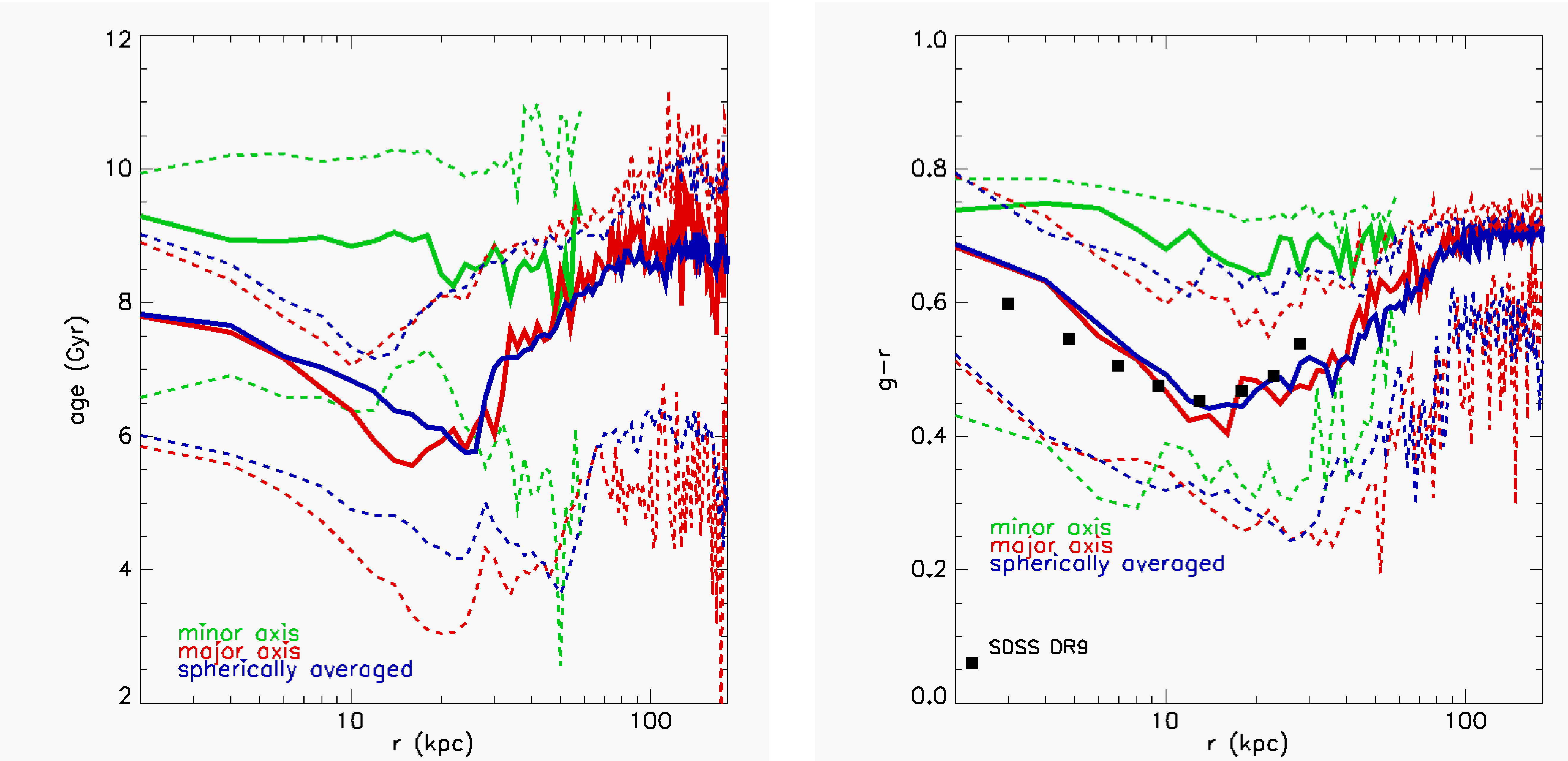
(g-r) spherically averaged and along the major/minor axes :



Good agreement with the observational (g-r) data for MW-mass galaxies (low concentration galaxies) in SDSS DR9 (D'Souza et al 2014).

4. Age profiles:

spherically averaged and along the major/minor axes :



The upturn in the colour (g-r) profile is created by older stars in the outer halo.

Conclusions

- We have studied the properties of stellar halos in the **Eagle simulations** and in **a new set of Eagle Milky Way zoomed simulations**.
- The Eagle zoom simulations allow us to probe in greater detail the structure of stellar haloes. **We tested them against a wide range of observed properties of halos (surface brightness profiles, [Fe/H] and colours) and find good agreement**.
- **[Fe/H] gradients are universal**. However, gradients are steeper along the major axis (or spherically averaged) than along the minor axis.
- The properties of stellar haloes can be explained with a mixture of accreted and in situ stars (**dual nature)**. The inner regions (< 30 kpc) of stellar halos are dominated by in situ stars and are flattened along the disc.
- **Observations of stellar halos should probe both the minor and major axes in order to get a full picture of the nature of stellar halos.**